Vol. XXXIX. JUNE, 1898.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

No. 821.

GEOLOGY IN ITS RELATIONS TO TOPOGRAPHY.

By JOHN C. BRANNER, Ph. D.*

PRESENTED NOVEMBER 17TH, 1897.

WITH DISCUSSION.

If there are laws governing the origin and development of topographic forms, nothing is clearer than that a knowledge of these laws must be of great importance to those who have to deal with such forms; and, indeed, there is a constant demand, among those who have not devoted much time to a study of the subject, for short and simple empirical rules for topography. There are such rules for topographic forms, but they hold good only in limited areas, and fail utterly whenever their general application is attempted. There is also a widespread disposition to appeal for explanation, especially of bold topographic forms, to the supernatural, to violent cataclysmic disturbances, subterranean upheavals, volcanic outbursts and "blow-outs," and to the Miltonian idea, in which: "The mountains huge appear emergent, and their broad, bare rocks upheave into the clouds." One serious-minded writer thinks the great gorge in the Cascade Mountains, through which the Columbia River flows, was made by God drawing his finger across that range.†

* Professor of Geology in Stanford University.

† Journal of an exploring tour beyond the Rocky Mountains, by Rev. Samuel Parker, Ithaca, N. Y., 1838, p. 215.

To arrive at any comprehension of topography, such ideas must be put aside at the outset; and the laws that mould topography to-day, the agencies which produce it, the materials worked upon, and how the work is done, must be studied before the results can be understood.

Topography is the expression of geologic structure pretty much as the outlines of the human body are the expression of its anatomical structure. To be more precise, topography is the resultant of the operations or eroding agencies and the resistance of the rocks, the time of their exposure, the initial position of the surface, and the orographic changes suffered. These are all fundamentally matters of geology, and the following generalizations may be laid down without fear of successful contradiction: first, that no one can understand topography unless he comprehends the geologic reasons for it; and secondly, that unless one understands topography he cannot represent it correctly. To set a man at work on topography who knows nothing of geology is very like having some one perform a surgical operation who knows nothing of anatomy.

"We see, according to the light that is within us." One cannot picture a subject he has not studied. However skilled a draftsman or artist may be in the technique of his art, unless he understands the animal or plant he has to draw, he cannot make a correct picture of it. In topographic representation this is equally true, and it is the more important because a large part of every map must be sketched in, and this sketching cannot be done properly unless he who does it knows what ought to be there. Unless the topographer knows what to look for he doesn't find it, or he finds only a part of it. This statement is based on no small amount of experience of this fact. It has been the author's duty to employ many topographers, and all his experience of their work has but confirmed this opinion.

It is of the utmost importance to the topographer that he should know what kind of topography to expect, and, to this end, the more he knows of the materials in which topography is cast, and of the agencies that shape it, the clearer will be his insight, the less waste of time and energy will there be, and the truer will be his representation of the relief.

The object of this paper is partly to point out the origin and controlling factors of some of the more important topographic forms, and

partly to show the necessity of a knowledge of geology—especially of structural geology—to the topographer.

Rocks the Material of Topography.

Topography as here dealt with is the representation of the forms of the earth's surface. These forms are impressed upon, carved in, or otherwise made of the soils and rocks of the earth's crust; but these rocks vary among themselves to such an extent, in hardness, structure, texture and position, that when subjected to the same shaping agencies they yield very different results. It is necessary, therefore, at the outset, that the topographer should have at least a general knowledge of the different kinds of rocks, what they are, how they originate, and of the forms of the masses in which they occur.

For the purposes of the present paper rocks may be classified according to the forms and origin of their beds as follows:

Water-bedded rocks or those laid down in water as mechanical, chemical or organic sediments.

Wind-bedded rocks, or those deposited on land in the form of blown sand or dust.

Organic deposits, or those made by living organisms, whether animal or plant.

Igneous rocks, or those cooled from a molten condition.

Origin of the Different Kinds of Rocks.

Brief descriptions of the methods of formation of these different classes of rocks will be given, in order that the forms of the deposits may be understood, and eventually the topographic relief to which they give rise.

The Origin of Water-Bedded Rocks.—Water-bedded or sedimentary rocks are those made of sediments, or fragmental, or skeletal materials, whether of mineral or organic origin, and laid down in water.

The sands, gravels, and clays washed by a stream into a lake or sea settle to the bottom and form beds of mechanical sediments. In time the sands form sandstones, the gravels make grits and conglomerates, and the clays make shales and slates. When the microscopic organisms that live in the sea perish, their skeletons sink to the bottom and

form beds of organic origin. Waves beat upon shores strewn with molluscan shells or upon coral reefs, break off fragments and grind them to powder, and this material is swept out by the undertow and sinks to the bottom to form sedimentary beds of organic origin. All these sedimentary deposits, whether they are coarse heavy cobblestones, small pebbles, sands or clays, are deposited in approximately horizontal layers in the bottom of the lake, sea, or ocean.

It is important to note also that the marine sediments are either carried down from the land by streams, or are taken from the immediate shores and carried out to sea by the undertow. It follows in either case that the heaviest sediments, the boulders and pebbles, sink to the bottom first and nearest the shore, while the finest silts, the clays, are carried farthest. The currents bearing the finer silts seaward are seldom checked suddenly, and the result is that the weight of the particles which can be carried in suspension decreases with the force of the current. For this reason, over any given area, the coarser sediments merge imperceptibly into the finer ones.

When, in the course of the earth's history, such beds are lifted from the sea bottom to form land, the peculiarities and local variations of these deposits must have some influence on the topography carved in them.

In the case of marine sedimentary beds, made up wholly or largely of the skeletal remains of microscopic organisms, the deposits are not so liable to local variations as are the mechanical silts. These marine organisms live in the water at or near the surface, and their remains sink to the bottom over large areas, while the uniformity in their sizes and weights offers but little opportunity for any selective action by currents.

Some water-laid beds are produced by chemical precipitation. In the case of salt lakes, where the water is being evaporated, when it reaches a certain density, the gypsum in solution is precipitated, and further evaporation causes the precipitation of the salt. The beds thus deposited settle over and conform to the bottom of the basin, and are therefore, in form, very like mechanically deposited sediments.

Wind-deposited rocks will not be discussed in this paper.

Organic deposits, other than those already mentioned, are coral reefs and peat beds. The coral reefs produce some of our limestone

beds, while lignite and coal have been formed from peat. The coral reef rocks are the skeletons secreted by coral polyps. The reef-building forms of these animals can live only in warm (68° Fahr.), shallow (less than 100 ft.) sea water, and they are thus obliged to extend their beds horizontally, except where by slow subsidence of the sea bottom they are enabled to grow upward.

Peat grows only in moist places, and for the most part in flat, marshy ones, such as the Dismal Swamp of Virginia. In the course of geologic time the peat becomes lignite, and still later coal. The interstratification of coal beds with marine sediments can only be accounted for by supposing the peat beds to have sunk beneath the sea, and that subsequent elevation permitted the re-establishment of the peat swamps.

Igneous Rocks.—The rocks that have been in a molten condition include the masses that have been poured out through the crust and over it as great lava outflows, those that have filled and cooled in cracks in other rocks, and also the materials that have been blown out by volcanoes and have fallen to the earth as ashes and scoriæ. Where these rocks have been spread over the surface as lava sheets, their early forms have been determined by the fluidity of the molten rock and by the surface over which they have spread. Sometimes they have been submerged after cooling, and sedimentary beds have been laid down on top of them. Where they have been intruded into crevices, their forms have been fixed by the crevices themselves. These are known as dikes. In the cases of fragmental materials blown from volcanic vents, the forms are limited to local accumulations lying in conical heaps. Sometimes these materials have fallen in water, and, settling to the bottom, have taken on the appearance of sedimentary beds, so far, at least, as their gross structure is concerned. Such beds are known as water-laid tuffs.

The Internal Changes Undergone by Rocks.

The materials of sedimentary rocks are at first soft and incoherent, but in the course of geologic time most of them become compact and hard, either from the pressure of other rocks heaped upon them, or on account of the deposition within them of cementing materials, or from a combination of the two, or on account of metamorphism or internal changes.

Angular rock fragments form breccias, pebbles and gravels; other coarse sediments form conglomerates, or pudding stones; sands form sandstones, and clays form shales or slates. The calcareous organic remains form chalks and limestones, while siliceous organisms make siliceous shales, diatomaceous earths, cherts, flints and jaspers. Peats form lignite and coal. Even the igneous rocks themselves are often greatly changed by being reheated or by the action of hot water. These changes are all internal; some of them are the results of physical forces, such as pressure, while others are of a chemical nature.

Structural Changes in Beds of Rocks.

Although the sedimentary rocks were originally laid down in approximately horizontal beds, yet, where they have been lifted from beneath the water, they have not always risen evenly. Their horizontality has been disturbed. They have been tilted this way and that, sometimes thrown into gigantic folds miles across, sometimes into wrinkles or close crumples, and sometimes they are broken, and the edges of the beds have slipped past each other. These last-mentioned breaks and displacements are called faults.

Folds and faults are likely to occur in groups, that is, gentle folds occur together, and closely squeezed folds occur together, but the two kinds are not often found in the same region. Folds may be long or short. Short folds often overlap each other slightly at the ends. The axes of folds are generally approximately parallel in a given area.

Faults are also disposed to parallel systems in a given region. They may be close together or far apart; and the amount of displacement may be anywhere between a fraction of an inch and thousands of feet.

It is of the utmost importance to the topographer that he should understand these folds and faults, for they frequently have a great influence upon the topography. Regarding the size, character or relations of folds and faults, there is no general law that can be laid down in anticipation of what may be found in any new region. Their distribution is seldom to be anticipated, but must be determined by a study of the outcrops. A knowledge of the methods of determining and locating these structural features is indispensable.

Topographic Relief.

If a lava stream emerges from beneath the earth's surface and spreads out over a wide area, it will, if a very fluid lava, form a flat surface by filling up the existing irregularities, much as if the region had been submerged by water and the water had frozen. If a volcano should burst forth upon a plain and should eject large quantities of pumice, scoriæ, ashes, and the like, these materials would accumulate about the mouth of the vent and build up a volcanic cone. In both instances the topography would be formed by direct construction.

If a part of the ocean's bottom should be uncovered or brought up and left as dry land, it would be found that this new surface had certain irregularities; but rain and frost and streams would soon begin to attack it, to cut channels in it and to produce topographic forms altogether different from its original surface. The new shore line, at first comparatively smooth, would at once be attacked by the waves, and a steep-faced bluff would mark the new beach. All this cutting and shaping of the new topography would be the work of removing or of destructive agencies.

These two general classes or agencies—the constructive and destructive—produce most of our topographic forms. They will be considered in this order.

Constructive Agencies and the Forms They Produce.

Subaqueous Forms.—Constructive topographic agencies, in the broad sense, should include subaqueous constructive forms; but while the forms of delta deposits and off-shore accumulations generally are constructive forms, they are of comparatively little importance, because after emergence they are usually soon obliterated. There are well-known instances, however, of such forms, and for that reason they will be briefly described.

When a stream carrying silts enters a quiet body of water, the checking of the current causes some of the silts to fall to the bottom. In fresh waters some of the finest particles remain for a long time suspended in the water, but the salts in salt water cause these fine particles to flocculate or cling together in little bunches and thus hasten their sinking to the bottom. Wherever a muddy stream enters a lake or sea the silts it bears fall to the bottom about the stream's mouth,

and, in time, build up deltas such as are found about the mouths of the Nile, the Rhône and the Mississippi.

These deltas, through the operation of floods, build up so as to rise above the average water surface. They are flat on top, while their seaward faces may slope off more or less rapidly into deep water. In outline they tend to be fan shaped. Wherever there has been an elevation of a delta deposit above water, the form has been found like that here described. The Great Salt Lake in Utah not long ago covered an area of 19 750 square miles, and the streams flowing into it made deltas, which, by the drying up of the water, have been left uncovered. Wherever the waves of that lake beat upon its shores, accumulations of considerable size and extent were formed. These deposits are now part of the surface relief of the region.

Spits and Bars.—Bars are formed about the mouths of streams by conflicting currents. When a stream enters the ocean its current tends to sweep the sands it bears out into deep water; but when the tide comes in, the current is reversed and flows up the channel of the stream, and these sands are carried in the opposite direction. The sands tend to accumulate on some middle ground where the currents balance each other, and here they build up a bar which, by the help of storm waves and high tides, may rise above the water. Sometimes conditions may favor the accumulation of these silts on one side of a stream's mouth rather than the other, and they may stretch across it, forming a spit.

Waves do not always break squarely against the shore, but more frequently the surf runs along the beach according to the angle of the wind with the shore. In some parts of the world the winds blow so constantly from one direction that the sands are always carried one way. When there is an obstruction on such a beach an eddy is formed behind it, and here the waves leave the sands they sweep along, and, in time, a long spit or neck is built, commonly hooked at the outer end.*

Emergent Forms.—Emergent forms of topography are those built up partly beneath the water, but gradually rising above it. Deltas built into dry land, lakes filled up with silts, turned into marshes, and later into dry land, are examples of this kind. Sometimes the fiords

* For a comprehensive discussion of the topographic features of shores see "Lake Bonneville." By G. K. Gilbert, Monograph I., U. S. Geol. Survey.

or submerged valleys along sea coasts have spits and bars formed across their mouths by the waves and the currents of the open sea, while in the quiet waters behind them the silts brought down by the streams are deposited until these bays are turned into marshes and then into dry land. In such cases there is an older and more precipitous topography diving beneath a new and nearly flat surface. The swamps near Oceanside, California, were made in this manner.

Storm beaches and coral islands rising above the surface of the sea are also constructive emergent forms of topography. River terraces are produced partly by the constructive and partly by the destructive work of streams. Stream valleys are filled with silts and débris at times of floods, and when the streams shrink they cut their channels down through these materials, and in shifting from side to side leave terraces along their courses.

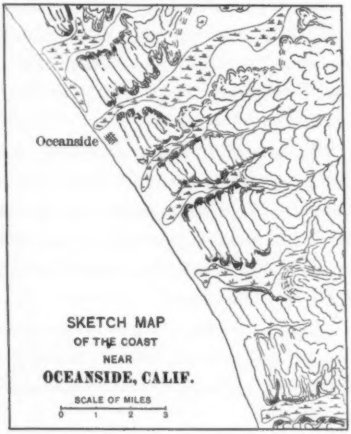


FIG. 1.

Subaerial Forms.—Subaerial forms produced by direct construction consist of volcanic ejectments and certain spring and geyser deposits. The surface forms assumed by lava depend upon the fluidity of the lava and upon the character of the topography over which it is spread. In the case of very fluid lavas the angle of the slope built up is quite low, while those less fluid stand at higher angles, or even bunch up in steep-sided heaps at no great distance from their vents.

The basaltic lavas are of comparatively easy fusibility, while the trachytic lavas are of difficult fusibility. Consequently, basaltic lavas form flat sheets or lava cones of low slopes, while the trachytes, emerging in an almost pasty condition, are disposed to form steep-sided cones. Part of these differences, however, is due to the difference in the sizes of the outflows.

The profile of the great volcanic mountain, Mauna Loa, Hawaii, has so low an angle, from 4° to 6°, that it hardly impresses a person

climbing it as a volcanic mountain. Some volcanic cones are made up largely of loose ashes, scoriæ or broken bits of rock that have been thrown into the air by subterranean explosions, and, falling near the vents, have piled up as cones of débris that stand at the normal angle of repose, which is from 33 to 40 degrees. The lavas of Mauna Loa are basaltic; those of Mount Vesuvius are also basalts very little different from those of Mauna Loa, but Mount Vesuvius is made up largely of scoriæ and ashes, while Mauna Loa is chiefly of fluid lava.

These general laws will give some idea of the methods by which such features are formed originally, and of the topography to be expected about active volcanoes. It must not be forgotten, however, that there are over the earth's surface a great many extinct volcanoes, and while these may still retain much of their primitive forms, they are more frequently than otherwise so modified by eroding agencies that their characteristic outlines have become partly or entirely obliterated.

One peculiarity of the erosion of cinder cones is worthy of note in this place: the loose materials on the slopes of such peaks allow the water falling upon them to sink beneath the surface at once. In this way these peaks avoid much surface erosion, but the water issues as springs about the bases of the mountains, and their erosion cuts backward into the cones.

Spring Deposits.—These are formed by the precipitation from solution of the mineral matter brought to the surface by subterranean waters. They are of local importance only and are omitted from this discussion.

Faults and Folds.—In a sense those forces which produce folds and displacements of the rocks may be looked upon as constructive. There may be, for example, fault escarpments, or freshly made folds, producing very marked topography. Such cases, however, are not so common as one might suppose, for the reason that the original outlines of features made in this way are soon modified by erosion to such an extent that they are thoroughly obscured or even entirely obliterated.

In the case, too, of both faults and folds the displacements often take place so slowly that erosion keeps pace with the movements, and the structural features produced by them never appear as marked topographic forms. In some cases, however, faults have produced marked topography. In most faulting there is a crack or break in the rocks,

and on one side of this break the edges of the fractured rocks are lifted above their former position, thus forming a step-like bluff. This escarpment may be from a few inches to several hundred feet high, and may be many miles in length. Such breaks are seldom straight, but have rough and more or less irregular edges, so that in detail a bluff produced by a fault is likely to be irregularly serrate or zig-zag in direction, although its general course may be approximately straight.

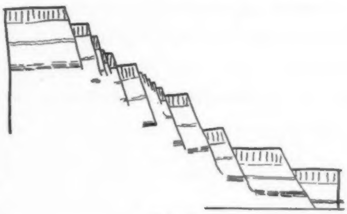


FIG. 2.

The surface forms that may be produced by faulting are almost as many as the forms of the fractures, depending upon the character and position of the rocks, the character of the force producing the faults, and the inclination of the fault face to the earth's surface.


FIG. 3.

Figs. 2, 3, 4 and 5 represent ideal vertical sections through the earth's crust. The upper surface in each case represents the surface of the ground. In Figs. 2 and 3 the faults have been produced by tension, while in Figs. 4 and 5, they have been produced by pressure. These faults may be close together or far apart, single or double, or they may branch out in different directions. While faults are not confined to any particular area

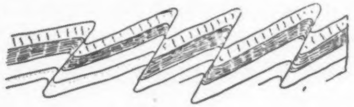


FIG. 4.

or rocks, they are much more abundant in some regions than in others, while in some they may be entirely wanting. In a given region faults often show a decided tendency to occur in parallel sets, and these may cross each other at rather constant angles. In the Coast Ranges of California, for example, the faults are for the most part parallel to the coast line and the main axes of the mountains (see Plate I).


FIG. 5.

The original folds of surface rocks have, as a rule, been so long exposed that their primitive forms have been entirely destroyed. The

long, narrow valleys of California, running parallel with the coast and with the Sierras, were produced originally by faults, but they have been greatly modified and widened by stream erosion. As in the case of faults, the folding of rocks has taken place so slowly that erosion has been able to remove obstructions as rapidly as they arose across the drainage. Even in cases of anticlinal ridges, there have almost invariably been thick overlying beds removed from them. The characters of folds will be discussed under the head of topography of "folded rocks."

Destructive Agencies and How They Operate.

Eroding Agencies.—Most topography is cut in the rocks of the earth's crust. All rocks exposed over the earth, whatever their origin, are subject to the action of those natural agencies that cut out topographic forms. These agencies act with such extreme slowness that it is not an easy matter to realize their importance, or even to believe that such vast results can be produced by such apparently trifling forces. If, however, one can realize something of the immense periods of time during which these agencies have been at work, there will be no difficulty in comprehending the results.

The agencies that attack, remove, and modify the land surface are as follows:

Water, in the form of moisture in the atmosphere, rains, springs, streams, waves and glaciers.

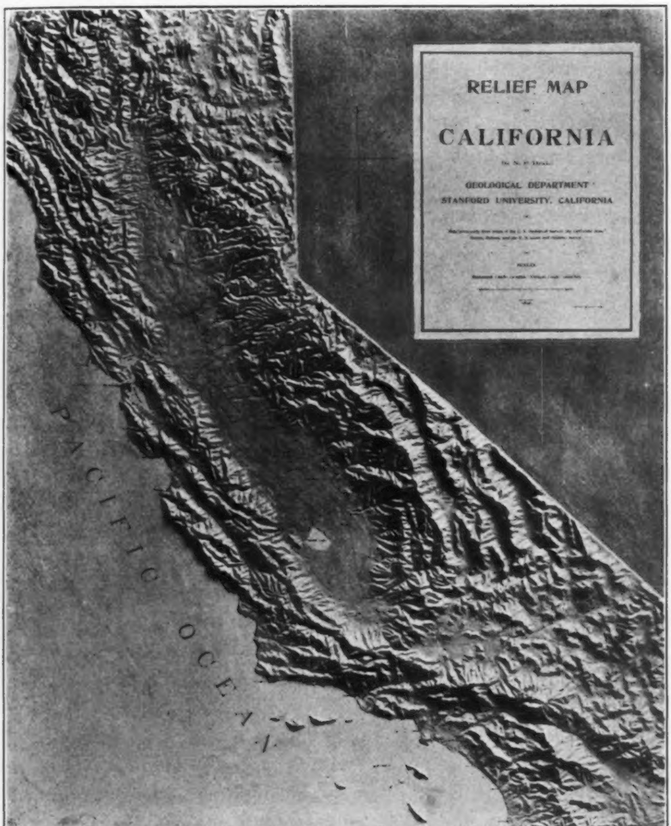
Atmospheric agencies, by means of winds, changes of temperature and frost.

Any agency that causes rocks to disintegrate or decay, or that removes them, either before or after they decompose, must necessarily influence the form of rock surfaces; but it is also to be noted that an agency may be active at one place and not at another, at one time and not at another, or under some conditions and not under others.

Moisture in the Atmosphere.—This affects the rocks by hastening the chemical decomposition of their constituent minerals.

Rains, Springs and Streams.—The direct mechanical effect of rain falling upon rock is of comparatively little importance; its chief work is done, not in falling, but as it flows away. A part of this water flows away over the surface, and a part sinks into the earth, passes through the soil and rocks, and, sooner or later, emerges as springs.

PLATE I.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIX, No. 821.
BRANNER ON GEOLOGY AND TOPOGRAPHY.



Before it enters the ground it usually absorbs more or less organic acid of one kind or another, and this acid greatly facilitates its chemical activity. In its passage through the rocks it dissolves more or less mineral matter out of them, and when it emerges as spring water it carries in solution considerable quantities of the mineral constituents of the rocks. No water has ever been found issuing from the earth that did not have more or less mineral matter in solution, while in some of these waters the quantity is enormous. In order to appreciate the amount of rock borne away from the land to the sea in this manner one need only determine the amount removed by a single spring or by a single stream.

In 1887–88 the author carried on a series of observations on the water of the Arkansas River, at Little Rock, where it was found that the dissolved mineral matter in one U. S. gallon of the water varied from 11 to 70 grains. The total quantity of mineral matter removed in solution in one year was 6 828 350 tons.

The materials carried down in solution in this stream are necessarily removed by water from the rocks over the hydrographic basin drained. Similar work is done by all streams, whether large or small, though the amount of material in solution in the water depends more or less upon the character of the rocks of the hydrographic basin. This is only the chemical work of water; its mechanical work will now be considered.

The simple fact that water flows off the land along the depressions is sometimes cited as evidence that these depressions have been made by the water. It is well said by those who object to this explanation of valleys that the water could not possibly flow elsewhere. This fact alone cannot, therefore, be regarded as evidence that valleys are made by streams.

The process of channel cutting will be better understood if a perfectly flat surface is assumed as exposed for the first time to subaerial conditions: rain, snow, frost, streams, changes of temperature, etc. If this flat surface has a gentle slope, the water falling thereon will flow down that slope, and the streams will unite and become larger as they approach its base. In time the running waters will wash out channels for themselves, and still later these channels will be worn deeper and wider. In such a case the channels are evidently cut by the streams.

If, instead of a flat surface, there is, to begin with, an irregular one having the same general slope, the water will seek the depressions from the outset, and the deepening of channels will proceed from these predetermined drainage lines. In both cases the details of the final relief of the region will be the result of the wearing and carrying action of the water. Velocity is what enables water to carry materials heavier than itself. It follows therefore that any increase in the slope of a region must increase the velocity of its streams, while the velocity of the streams increases their carrying power. This relation of force to velocity is expressed by the formula: $F \propto V^2$, in which F is the force of the current and V is its velocity; but the power of the water to move stones varies as the sixth power of its velocity ($F \propto V^6$); that is, by doubling the velocity of a stream, its power to carry is increased sixty-four times.* Hence, any increase of the current of a stream enormously increases its power to sweep along the materials in its channel. It follows that the amount of materials carried along by a stream must vary greatly if the stream itself is subject to fluctuations of volume.

Some streams are always muddy, others only occasionally; but all muddy streams are so because they carry large quantities of mechanically suspended matter. The amount of material carried by such a stream as the Mississippi or the Amazon is almost beyond belief. The observations made by the author upon the Arkansas River, at Little Rock, show that that stream carries, in addition to the dissolved matter already mentioned, an enormous amount of fine sand and clay. At times this amounted to more than 700 grains to the gallon. The total amount of mechanically transported sediment carried past Little Rock in the year was 21 471 578 tons. The total amount carried down both in solution and in suspension, in the year was 28 299 929 tons, or equivalent to a cube 749.2 ft. on each side.

Similar determinations of the silts of the Mississippi River show that it carries out of its hydrographic basin every year a mass of mineral matter equal to a cube 1 954 + ft. on a side, without including the dissolved matter. This material can only come from the basins of the streams, and these determinations afford the means of ascertaining the rate at which the land surface is being removed.

* A Treatise on Hydraulics. By F. Merriman, New York, 1891, pp. 251-252.
"The Suspension of Solids in Flowing Water." By E. H. Hooker, Trans. Am. Soc. C. E., 1896, Vol. XXXVI, pp. 239-340.

Over the entire Mississippi basin erosion goes on at the rate of a foot in 5 000 years; over the Arkansas basin at the rate of a foot in about 9 000 years; over the basin of the Danube at the rate of a foot in 6 846 years; over the basin of the Rhône at the rate of a foot in 1 528 years; over the basin of the Po at the rate of a foot in 729 years, and over the Ganges basin it is at the rate of a foot in 823 years. The importance and bearing of this matter upon topographic relief will be seen presently.

Waves.—Waves do their chief work on the larger bodies of water—oceans, seas and large lakes. Although they are confined in their operations to narrow vertical limits, yet their force is irresistible, their work sharp and well defined, and the length of the lines along which they operate is coextensive with the shores of every ocean, sea and lake on the globe. Their work consists in undercutting the shores, rolling the talus back and forth, and thus grinding up the coarser materials. These materials are either thrown on shore as shingle and sand or are swept out into deeper water by the undertow.

The effect of waves is important only on or near the beach, for they do but little work 20 ft. below low tide or 50 ft. above high tide, except by undermining. When it is recalled that almost every part of the earth's surface has several times passed through a beach condition, the important part the waves have played in the earth's history may be suggested.

Glaciers.—In those parts of the earth in which precipitation takes place in the form of snow, the drainage is in the form of ice streams or glaciers. These glaciers carry down upon their surfaces, or within the ice, whatever rock fragments or soils may fall upon them, or that the ice can scrape from its rocky bed; and when the slowly moving ice reaches the point where it melts, this load of débris is dropped, or is swept along by the stream that flows from the melting glacier. The accumulations at the ends of glaciers are known as moraines. If, in time, the glaciers become much shorter, these moraines are left strewn over the ground formerly covered by the ice.

Atmospheric Agencies.

Winds.—In their direct action winds modify the earth's surface by moving sand dunes, by carrying dust in arid regions, and the ashes of volcanoes, and by forming natural sand blasts that cut and polish the rocks.

By their indirect action they are of even more importance, for they affect vegetation on the land, distribute moisture over the earth, help determine the force and direction of ocean currents, and, by raising waves upon water surfaces, enable the waters to undercut their banks and encroach upon the land in some places and to fill up and build beaches, spits, and bars in others.

Changes of Temperature.—These tend to break up rocks by causing them to expand and contract alternately. The minerals of which the the rocks are made do not all expand and contract alike in these changes of temperature, and this tends to pull the rock to pieces and allow acidulated waters to penetrate the crevices and finish the work of destruction.

Frost.—The expansion of water freezing in crevices of the rock hastens its disintegration. By the alternate freezing and thawing the rocks are rapidly broken to pieces and exposed to other decomposing agencies.

The Forms Produced by Destructive Agencies.

Most gorges, cañons, narrow valleys and stream channels are cut in the rocks by streams and other disintegrating and eroding agencies, while topographic prominences are simply the parts left behind in relief. Hills and ridges are therefore high, not because they have been thrust upward, but because the country around them has been worn down more rapidly than they, and it is fair to assume that hills and valleys started very nearly at the same elevation. Although topography is thus chiefly the resultant of rock resistance and rock removal, the resisting powers of rocks vary so much, and the removing agencies work so differently under different conditions, that the problem, in its details, is a complex one.

Other things being equal, topography is dependent upon:

The character and alternation of the rocks.

The geologic structure, or the position of the beds, dikes and veins.

The slope of the land surface.

The climatic conditions.

Interruptions during development.

The initial, primitive conditions or starting point of the drainage.

The length of time the region is exposed to eroding agencies.

The nature and working methods of the eroding agency.

There may be any combination of these influences shaping the topography. However complex the combinations may be, these agencies, when acting alone, produce comparatively simple results.

The Character and Alternation of the Rocks.—It has been stated that erosion goes on over the hydrographic basin of the Mississippi River at the rate of a foot in 5 000 years. It is hardly necessary to say that this erosion is not even, that this foot is not removed over the whole basin alike, but that it is simply an average for the entire area. At some points erosion is almost nil, while at others it is more than 1 ft. in that length of time. If in starting there were a perfectly flat, smooth surface having a gentle slope, the first rains might flow off as if from a sheet of glass; but this water would soon begin to wear here and there, and this wearing would always be more marked in the regions of soft rocks, and in a short time there would be developed, over this once smooth surface, a system of drainage that would come more and more under the influence of the rocks; that is, the channels would be cut deeper and deeper in the soft beds, while the harder ones would be left as prominences. This is shown in Figs. 6 and 7, which are sections across alternate upright beds of hard and soft rocks.

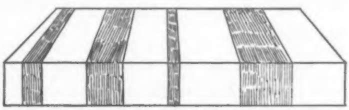


FIG. 6.

Under such circumstances in topographic development the alternation of hard and soft beds must determine the location of valleys and ridges, and any rearrangement of these beds would produce a corresponding rearrangement of the valleys and ridges. In the case of igneous rocks, often the molten material issues through crevices in the older crust, and, as these crevices vary greatly in form, the dikes that fill them vary as much. These dike rocks may be either softer or harder than the beds they penetrate. When they decompose more rapidly than the surrounding rocks, they form depressions; when they are more resisting, they stand out as ridges or walls upon the surface.

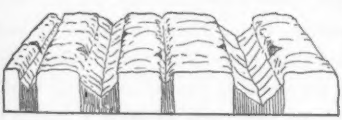


FIG. 7.

When they are of equal resisting power with the adjacent rocks, both wear away together without differentiating the topography; but

whether these dikes make depressions or ridges, no definite law can be laid down for their direction. They sometimes follow parallel lines; sometimes they radiate from centers, and sometimes they seem to bear no apparent fixed relations to each other.

When the rocks are massive and homogeneous throughout, as in the case of granites and some gneisses, there are no marked lines of weakness to encourage selective action of erosion. These rocks, whether in large or small masses, frequently exfoliate or peel off, like the coats of an onion, and produce rounded or ball-like boulders of decomposition, or, on a large scale, they form dome-like hills and mountains.

These forms are characteristic of massive rocks only. They are well illustrated by Stone Mountain, in Georgia,* and by the exfoliated boulders and peaks of Brazil.†

The destructive work done by water in dissolving the mineral constituents of rocks has been spoken of. It follows that the more soluble rocks are affected by chemical activity more rapidly than those less soluble. Limestone is one of the most soluble rocks, and for this reason it is everywhere attacked by water and removed in solution. Water does not confine its action to surface exposures, but penetrates the crevices in the rocks and attacks them often far beneath the surface. The removal of large quantities of rock from deep down below the surface gives rise to caves, sometimes of vast extent. Often the caves are not far below the surface, their roofs give way, the soil slides down and, concealing the old cavities, forms what are known as sink-holes. These sink-holes are filled with water, and ponds mark their positions. Caves and sink-holes are confined for the most part to the regions of limestone rocks, and the drainage of such a region is frequently almost all underground.

The Geologic Structure, or the Position of the Beds, Dikes and Veins.—Rocks do not always stand on end, as in the case supposed above, but lie in every conceivable position, from horizontal to vertical, or are even overthrown. They are bent into broad, gentle folds, or squeezed into close wrinkles, or are broken by faults and tipped about in all kinds of positions. It is not necessary to consider what caused these

* A Treatise on Rocks, Rock-Weathering and Soils. By Geo. P. Merrill, N. Y., 1897. Frontispiece. North Carolina and its Resources, p. 115.

† Decomposition of Rocks in Brazil. Bul. Geol. Soc. Am., VIII, pp. 272-277.

folds; it is enough to know that they exist, and that the axes of the folds are not necessarily parallel.

As a rule, streams and eroding agencies avoid hard rocks and seek out the soft ones. It follows, therefore, that this selective power of water in attacking the rocks must produce different topographic effects according to the positions in which the rocks stand. Indeed, erosion is entirely guided by the rocks in many cases, while in all cases they direct it to a greater or less extent.

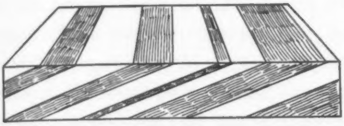


FIG. 8.

Beginning with the flat, smooth surface shown in Fig. 8, as in the previous instance, beds of the same kinds and in the same relations to each other will yield a topography suggested by Fig. 9, the streams following the soft (shaded) beds down the dip. Fig. 10 represents alternate hard and soft (shaded) beds dipping in various directions.

In a region of gently dipping rocks, the streams, following the strike of the beds, move down the slopes at right angles to their courses. Folded beds yield a great variety of forms according to the character of the rocks, the nature of the folds and the age of the topography. But they all follow the same general law; erosion removes the soft beds, the harder ones are undermined in some cases, in others they stand out as rock walls.

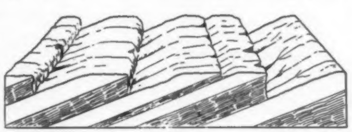


FIG. 9.

The accompanying sketch map (Fig. 11) of the country near Conway, Ark., illustrates well the influence of hard and soft beds in a region of folded rocks. Here the almost unbroken ridges of sandstone can be traced for many miles, swinging around the anticlinal noses and back again around the synclinal spoons like the hard and soft grain of a pine board. Round Mountain in this area is made up of such layers worn away till their remnant looks like a nest of gigantic dishes.

FIG. 10.

When the alternate hard and soft beds are horizontal, as in Fig. 12, the topography is different from any of these forms. In this case the

soft layers may be removed by the action of frost, or weathering in various ways, or by water flowing down the face of the bluff. In either case the removal of the soft layers undermines the hard beds and these eventually break down in blocks. As this process goes on, the profile of the hill does not necessarily change much beyond a certain point until late in the life of the hill, when the hard layers will be removed one by one. Where the beds are thus horizontal they tend to make a terrace or step-like topography. If, in a region of horizontal rocks, the valleys are short and narrow, the slopes will be more or less even, but where the streams, either through the age of the drainage or the width of the valleys, have meandering courses, there

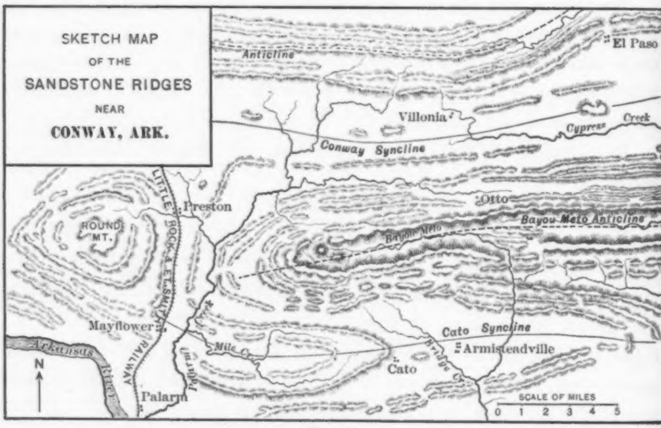


FIG. 11.

will be a marked variation in the slopes of the opposite sides of the streams. Such topography is represented in Fig. 13, which is that of a meandering stream, and is common in certain portions of the Ozark mountains of Arkansas and Missouri.

If, instead of alternating hard and soft beds, we have horizontal rocks nearly uniform in character, they frequently form tall, slender columns; "pulpit rocks," or "chimney rocks," as they are often called. The flatness of a plain is sometimes due to the exposure over its floor of a resisting horizontal bed.

The foregoing discussion of the development of topography in regions of sedimentary rocks has proceeded on the theory that the beds

are uniform in thickness and constant in character. As a matter of fact, there is no such uniformity in the rocks in Nature, and the reason is apparent when the conditions under which the beds have been formed are considered. This variation in thickness and character, this changing of a sandstone into a shale a mile away, and to a limestone further on, yields a corresponding difference in the topography developed from these rocks. Ridges prominent at one place die down and are replaced by valleys and are overlapped by others which here are insignificant and further on are bold and mountainous.

FIG. 12.

It should be noted in regard to the structural forms spoken of here or elsewhere in this paper, that they are not always, or even commonly, seen exposed in Nature. They are, for the most part, concealed by soils, undergrowth or forests, and these structural features can only be made out by the study of wide areas.

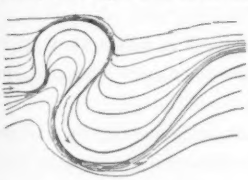


FIG. 13.

Owing to the peculiar method of attack on sea shores - along a horizontal line — structural features yield characteristic forms where cut by waves. Where hard and soft rocks stand on end and their strike is at right angles to the general coast line, the details of the shore will be very irregular owing to the yielding of the soft beds and the resistance of the hard ones, as represented in Fig. 14.

If the beds are tipped up and dip toward the water, the sloping beds will act as an effective breakwater, against which the waves can have but little power. If the beds are horizontal or dip away from the water, the waves will undermine them by attacking the soft beds at their lower exposures.

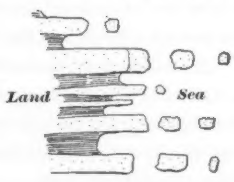


FIG. 14.

Under other heads are discussed various influences that affect the details of topographic relief. Each of these influences is important in its own place, but there is no one of them that so uniformly and so persistently moulds topographic details as does geologic structure. For this reason especial attention should be given to the structure

when it becomes necessary to understand or represent the topography.

The author has been asked to explain the rules for topography suggested by M. L. Lynch, M. Am. Soc. C. E.* The first rule is: that with "a stream flowing east or west * * * the south slope of the valley is generally steeper."

This rule holds good in a region in which the rocks have a gentle south dip, but not elsewhere. If the rocks dip north at the same angle, the steep slope will be on the north sides of the streams.

The other rule is that "in a stream flowing north and south, the east slope of the valley is invariably steeper." * * *

This rule holds in a region where the rocks have a gentle east dip, and not elsewhere. If the rocks dip west and the streams flow north or south, the steep slopes will be on the west sides of the streams; in other words, both rules would be reversed if the dip of the rocks were reversed.

Such rules may be most useful in the regions in which they originate, but they are of no value, and may, indeed, be very misleading in a region of different geologic structure.

The Slope of the Land Surface.—From what has been said of the transporting power of running water (p. 66), it follows that streams with steep gradients carry away whatever materials lie in or fall into their channels much more rapidly than those with lower gradients, in accordance with the formula $F \propto V^6$. Besides carrying away sand, gravels and boulders, such streams corrade, or, by means of the impact of the moving materials, wear and cut their beds; and as increase of velocity is a factor of so much importance in this connection, it follows that the slope which produces the velocity is the prime factor.

If a slope were perfectly even, if the rocks were of the same character from top to bottom, and if the stream were of the same size throughout, the cutting along its channel would be uniform from one end to the other. But the gradient of every stream varies more or less from one part to another. The rocks also vary, and there is, therefore, a tendency for it to have alternate cataracts and slack currents. The long slopes of mountain chains are frequently not eroded most rapidly at their steepest parts, but this is due to the fact that these steep grades are near the crest where the streams are small. In

* *Trans.* Am. Soc. Civ. Engrs., 1894, xxxi, p. 82.

Fig. 15, if the full line represents the slope of an original surface, the amount of erosion down the slope would be indicated by the distance between the full and dotted lines.

Whatever deviations from this rule are found are due to other conditions, such as variation in the rocks, structure, changes or time. In general the elevation of a country, by increasing the slope, affects the topography by increasing the velocity of its streams, and hence their rate of erosion, thus allowing the formation of deep gorges.

Climatic Conditions.—Inasmuch as topographic features are carved chiefly by running water, it follows that there is but little carving done in regions without water. Perfectly arid countries therefore are subject to but little change from this cause.

The wind-blown sands, and the breaking up of surface rocks by changes of temperature, are the most potent agents of change in such regions. In cases, however, in which streams flow through these regions, they produce very marked topographic effects, owing to the fact that they erode their beds and clear their channels, while the walls forming their banks are but little affected by the climate.

There is no more remarkable illustration of this peculiarity of the work of streams in an arid region than that of the Grand Cañon of the Colorado, where the Colorado River, rising in a region of heavy precipitation, in the Rocky Mountains and Wasatch Mountains, flows southwestward across the arid regions of Southern Utah, Northern Arizona and Southern California.

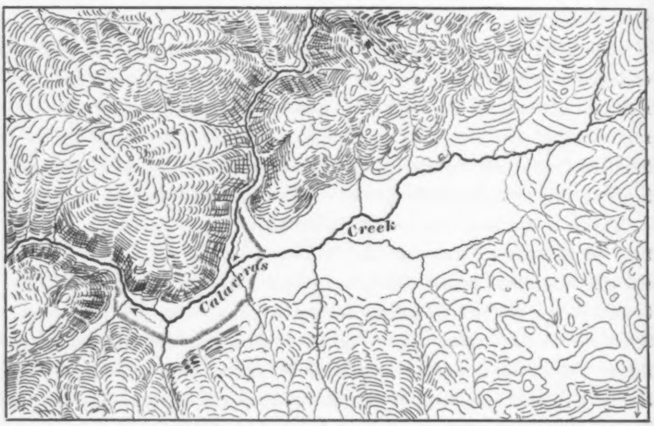
FIG. 15.

Interruptions During Development.—The crust of the earth is nowhere perfectly stationary, but is constantly, though for the most part imperceptibly, rising or sinking. Now, if elevation takes place across the channel of a stream, the stream will cut through the obstruction if it does not rise too rapidly. In most cases such changes during the life history of a stream, do not involve great elevations, but in some instances there is the spectacle of a river cutting a deep gorge through a mountain.

If an elevation across a valley takes place more rapidly than the stream can cut, a lake will be formed. Such instances are known, but they are not common. In a mountainous region the streams are rapid; therefore they cut faster than they otherwise could, and obstructions, in order to make lakes, must rise too quickly to be cut down at an

equal rate. A lake made in this way is soon filled up with silt. Immediately thereafter the outlet cuts the dam down slowly, and the stream sinks through the silts of the former lake, leaving terraces on the sides of the valley.

Calaveras Valley in Santa Clara County, California, was formed in the manner here indicated. The accompanying sketch map, Fig. 16, shows the flat floor of this valley with steep mountains on all sides. The obstruction was at the lower or northern end of the valley, and is now being removed by the stream. In such instances the downthrow must always be on the up-stream side of the fault.



SKETCH MAP OF CALAVERAS VALLEY, CALIF.

ONE MILE

FIG. 16.

The Initial, Primitive Conditions or Starting Point of the Drainage.—It often happens that folded and faulted rocks of various characters have been sheared or smoothed off by erosion, and that the area has then been submerged, and sedimentary beds have been laid down unconformably on the older rocks; or lava sheets have been spread over these eroded beds without their being submerged. Whatever the drainage and topography may have been before the lava was spread over the area, or before the superposition of the new sediments, the new drainage will be more or less different from the old on account of the form of the new surface. The streams, starting under the guidance

of the new topography, begin to cut their channels through the new rock, and sooner or later reach the old buried rocks. By the time the buried topography is reached, the stream is so closely confined to its channel that it is obliged to cut through the underlying rocks and to cling to its new channel regardless of the old topography. Such a system of streams is called a superimposed drainage, on account of its being let down from overlying beds regardless of the rocks in which it now runs. It should be noted, however, that when a buried topography is uncovered in this way, although the older rocks are unable to bring the drainage under immediate control, there is a constant tendency in that direction. Streams can in this way cut hills and ridges in two, but the rocks that form such ridges are simply notched like a board; lateral streams soon bring them into relief again, and the continuity of the beds can be traced across the principal streams. Erosion seeks out the soft beds again and avoids the hard ones—it goes in the direction of least resistance. The result is that the smaller streams are soon brought again under the control of the structure. Aside from the principal drainage lines, the chief topographic features, even in the case of a superimposed drainage, are controlled by the geologic structure.

The Length of Time the Region is Exposed to Eroding Agencies.—It has already been shown that when destructive agencies get access to a piece of the earth's land surface they begin immediately to attack it, to cut it down and wash it into the ocean. The general tendency of this operation is gradually to reduce the land surface to a low level. Before this level is reached, however, the topography passes through a series of changes, and these changes vary according to the characters of the rocks, geologic structure, climatic conditions, accidents during the period, slope of the country, etc.; or, to put it differently, starting with a given piece of structure, the topography will not always remain the same, even in form, but will vary more or less with its age or with the length of time it is exposed to eroding influences. It is generally agreed that sharp rugged outlines, high and steep relief, waterfalls and rapid streams are characteristic of new topography, and that low relief, rounded outlines, and sluggish streams indicate an old topography. Within certain limits these are characteristic features of old and new topography, but there are many important exceptions.

The Nature and Working Methods of the Eroding Agency.—With important exceptions erosion is done only by water and by ice in motion. The cutting of gullies, cañons and valleys, by streams, has already been explained. The removal of the walls above the stream-bed is greatly hastened by the changes of temperature and especially by the action of frost which loosens and disintegrates the rocks and causes them to slide down the slopes. When precipitation is only in the form of snow, the drainage of the region is effected by glaciers. These streams of ice follow the low ground like streams of water, and carry upon their surfaces, or within their bodies, or push over their rock floors, the soil and rock fragments that come within their reach. The stones, held fast by and pushed along in the ice, grind and wear away the hard rocks in place, rounding off the projections on the up-stream side. In cases of continental glaciers, such as those which now cover the antarctic regions and most of Greenland, it is reasonable to suppose that the up-stream sides of the hills that lie buried beneath these ice sheets are worn more than the down-stream sides. Geologists have found that a large part of the North American continent, nearly all the islands of Great Britain, all of Scandinavia, and large portions of Northern Europe, were once buried beneath a similar sheet of ice. This ice moved, not from the north toward the south as was formerly supposed, but from certain centers outward. It everywhere affected the topography, in many cases leaving the hills more or less rounded on the uphill side, and everywhere strewing the débris over the country, and frequently piling it up in heaps and lines or moraines. The topography produced by ice is characteristic, and there is usually a strong contrast between glaciated and non-glaciated areas, even when the rocks in each are the same.

After this brief statement of the processes by which topographic forms originate and change, it is hoped that the original proposition may be accepted, at least to this extent: that there is not, and cannot be, a fixed rule for all topographic forms, and that in order to understand topography one must understand geology.

"That none but a geologist can make a map is evidently true from the fact that we only see what we look for, and the geologist alone looks for surface indications of internal structure; he knows, therefore, the importance and significance of what to any other man is nothing, or at best a curiosity." *

* Manual of Coal and its Topography. By J. P. Lesley. Philadelphia, 1856, p. 192.

DISCUSSION.

J. F. KEMP, Esq.—When pure science is taught to engineers, the pressure is always strong to put it in a way that will have a direct bearing upon their future professional work, and the speaker does not know that in any other way geology touches engineers so closely as in this matter of topography. Mr. Kemp.

The United States are perhaps a little backward in the preparation of topographical maps. There have been many maps of their territory of greater or less excellence, in which everything has been plotted on a flat surface; but it is only within recent years that the incompleteness of a map which shows the Rocky Mountains and the Great Plains in the same manner has been appreciated, and only lately has there been a marked tendency toward the preparation of those with contours, as being the only satisfactory way of delineating a country.

Where the relief is pronounced, as it is in many regions, geometry of three dimensions instead of two must be used. But to understand topography, and particularly to transfer it correctly to paper, the engineer must comprehend the geological structure and history of the area in question.

The United States Geological Survey has made great endeavors to place good topographical maps in the hands of the people in all parts of the country at a small cost. The scale of these maps is about 1 in. to the mile, with 20-ft. contours, which are not, of course, located with mathematical accuracy, but which are very satisfactory considering the amounts expended. If a line is required to be run for a canal or an aqueduct, the surveys have to be elaborated, and in much greater detail than is shown by the maps. Nevertheless, in developing the accuracy that is within the means of attainment, the Geological Survey has called upon topographers to cultivate an artistic sense, and to be able, by careful practice and study, to sketch the physical features of the country with a close approximation to the truth, and the speaker was sure that all who have tested these maps in practical work are convinced that they are a marked success. The same artistic sense is demanded of the topographer as is expected from the painter in portraying a face. Such a man studies his subject with care, and it is in the catching of the individuality that the success of a portrait lies.

The topography in the vicinity of New York City, being closely involved with the geology, serves well as an illustration of this paper. It consists of a number of ridges, running in a direction generally northeast and southwest, and divided by valleys which are quite pronounced.

The valleys, of which the channel of the Harlem River is a type, are all located on a soluble and easily eroded limestone. The crossing of this depression by the invert of the new Aqueduct showed a lime-

Mr. Kemp. stone belt immediately beneath the river itself, and subsequently the same formation was found in the East River when the gas tunnel was put through to Ravenswood. In the east channel on the east side of Blackwell's Island, a beautiful belt of limestone, 200 ft. or more in length, was found right under mid-stream. In the west channel there was much trouble owing to the products of decomposition which are the invariable associates of the limestone in this region. There is every reason to think that the North River also flows on an old limestone belt, and Dr. Merrill, of the State Museum at Albany, believes he has found evidence to demonstrate that this holds true as far north as the Highlands. Many of the tributary streams come in over limestone valleys. The great dam in the Croton River valley has had to deal with this rock in its bed. There is a limestone belt north of the city on the east side of the Harlem River, where it branches at Jerome Avenue, and the Harlem Railroad is in another belt. In fact illustrations might be multiplied in almost every valley in Westchester County. There are also other points about the topography here that are equally significant.

In his paper the author does not follow out the development of drainage systems perhaps to its full conclusion. It is known that as rivers are seeking their lines of passage towards the sea, they pick out the weak spots. In the course of time they will establish a gradient that is just sufficient to carry off the water, but not enough to transport sediment, and if during floods they are laden beyond their capacity, on the subsidence of the water the sediment may drop, even in the channel itself, and restore the old gradient. Rivers tend to reach a base level, as it is called, and after that is attained they meander across the country until it is all reduced to a practically level surface with a slight slope from the heights down to the sea. If the surface is elevated in the course of geological time the rivers will once more begin to excavate their valleys, and will appear first in deep cañons, then in widening valleys until the elevations are simply stumps of the old plains that once existed. If anyone in this vicinity from a high building, or from one of the heights further up the river, views the sky line, he will be impressed with the fact that it is singularly even. There is no elevation, even in the Highlands of the Hudson, that projects above the general line. If the depressions are eliminated from the view, the horizon appears the same as if one were on the prairies. It is clear, even to superficial observation, that this surface must have once been level and continuous in past times, and that it has been eroded and trenched in the valleys. The mountains really are only the stumps of this old level surface, despite the fact that when sailing up the Hudson one may look up at Storm King and Dunderberg and the other hills and think oneself in the presence of no inconsiderable peaks.

Another point that is of geological nature, but that enters prominently into the topography in this region, is the gravel and the soft deposits left on the surface of the hard rock by the retreat of the glacier in the immediately preceding geological period. The line of hills that make the backbone of Long Island, on the north shore, and that is succeeded by the flat drainage plain further south, is a good illustration, and the hummocks and little hills and ponds in a small way on Staten Island will appeal to any observer at all familiar with glacial matters as extremely significant evidence of the presence of ice here in the past. If one were to make a topographical map, which would be at all expressive of the country in this region, it would be necessary to bear in mind these various features; or—to put it the other way—if a topographer had in his mind the course of geological development through which this area had passed, he would be able, with greater fidelity and truer appreciation of the problem before him, to place its relief in three dimensions on paper. It must also be remembered that in the past the country has been submerged, and one or two striking illustrations of this fact may be cited. Up the Hudson River may be noticed the marked promontories of gravel, resting on the clay beds that are so much used for brick. If one considers that those gravels are delta deposits, and that they are opposite each stream that comes in from the side hills, one is immediately convinced of the fact that the land has been under water. In reality there are exposed to view models which illustrate some of the problems that the engineer engaged on river and harbor work has to wrestle with in order to preserve channels clear, and keep the sediment of a stream from entering still bays and choking water-ways needed for commerce. In the Adirondacks, in the valley of Elizabethtown, or in the Keene valley, and all along on the north side of the mountains in the vicinity of Saranac Lake, old lake basins are shown with wonderful fidelity. The meadow land on many of the streams has that flat surface which is characteristic of exposed lake bottoms, and each little brook has a succession of terraces, showing, as clearly as a model made for the purpose, the deltas built up by these streams in the past when they flowed into the still water of the lake. Mr. Kemp.

As stated at the outset, it has often been a serious problem with teachers of geology in engineering schools, who, like the speaker, have to prepare a constituency of young men for their work later on, just in what way to put the subject in order that it may be of the greatest use to them in the future; and more and more, as time has gone on, has the speaker realized the importance of the development of topographical relief from the study of past conditions.

Probably the members are aware that geography of late has taken a new departure, and that the linking together of the geological and the geographical has given rise to what is called the new geography.

Mr. Kemp. The better teachers of to-day, in placing geography before even the children in the schools, have always topographical relief in mind as something which has developed in the course of time, and which is dependent upon the relative hardness or softness of rock, upon erosion of streams and elevation or depression of land. Thus, the study of geography to-day is not so entirely a matter of political boundaries as it used to be; and experienced teachers find that by the handling of little collections of rock, and the like, the child's attention is drawn to these features, and the child himself is led to apply his observation to the interpretation of Nature as it lies about him. In a larger way, and with students of more mature years, the general experience has been that it is upon this side of the subject that the greatest stress should be laid, and if any of those who take part in this discussion can throw out hints from their experience that would be of value to at least one teacher, they would be very gratefully received. In geology, as taught to engineers to-day, it is not so much a matter of fossils and the dead past, as it is placing in their hands the key to many topographical structures with which they will have to deal in the future, and the making clear to them the development of the surface of the earth that is all about them.

Mr. Meem. JAMES C. MEEM, Assoc. M. Am. Soc. C. E.—It was the speaker's good fortune to be connected for some years with the United States Coast and Geodetic Survey's transcontinental triangulation, which has just been completed. He was on this triangulation during the observation of the great quadrilateral in the Wasatch Mountains, the largest observed quadrilateral in the world. It is made up from Ogden Peak on the northeast, Mount Nebo on the southeast, Pilot Peak in Nevada, and Mount Ibapah on the southwest lying just east of the Utah and Nevada line. These peaks are from 9 000 to 12 000 ft. in height, and the speaker was on three of them during two seasons. The country in that vicinity is possibly as interesting, geologically, as any in the world. There is the Great Salt Lake Basin, and beyond that the desert. The Great Salt Lake contains about 17% salt, while the ocean has only about 3 per cent. The water is so dense that, when bathing in it, it is impossible to sink. Beyond the lake for perhaps 60 miles in a westerly and 150 miles in a northerly and southerly direction extends the Great American Desert. Except for a few mountains, which rise abruptly from its surface, it is a plain absolutely void of any kind of vegetation whatever. It is crusted over with a thin coating of salt. In the winter there is a little snow which dissolves the salt, and in summer it is dried again. To a geologist it should be a simple problem to decide how long the lake will continue to exist. There is an interesting feature connected with this region which shows that the ocean once covered it. The bench on which Fort Douglas is built extends around the lake and desert region, and

can be found at the same elevation on the other side, which shows evidently that the region was once covered by a large body of water, possibly the ocean. The ocean must at some time have broken through, or the land must have been elevated, and the subsequent evaporation of a portion of the water over this region accounts for the desert, as well as for the marked salinity of the lake water. Mr. Meem.

There is an interesting formation at Mount Ibapah. There are two peaks rising above the ordinary range, and about 6 000 ft. above the valley. One of these is of white sandstone, and the other of red sandstone, and their bases touch one another. The speaker has no explanation to offer for this phenomenon.

CORRESPONDENCE.

N. H. WINCHELL, Esq.—The writer desires to express his entire concurrence with the views of the author as to the necessary relation of geology to topography, and the dependence of the latter on the former. The face of the earth is nothing but what geological forces have made it—at least in so far as those features are concerned which have to be represented on a topographical map. He is the best topographer who most correctly represents those features; and he also is more likely to correctly represent those features who is the better equipped with proper instruments, skill and knowledge. Mr. Winchell.

It is necessary only to consider whether a knowledge of geology can be counted among the needed qualifications of the topographer. It may be thought by some that a topographer simply, *i. e.*, a civil engineer who is expert in the manipulation of nice instruments and the tracing of delicate lines on the sheet, has all the necessary qualifications of a topographer without a knowledge of the geological structure, *i. e.*, without taking into account the internal structure, the anatomy and physics of the earth, he would more correctly delineate the actual surface than he who may be influenced by a knowledge of such structure; and it has been claimed that the geologist is unfavorably affected by what has been denominated his "personal equation." That, however, is a very shallow and incorrect view. What would be thought of a painter who, without looking beneath the surface and considering the sentiment, the passion, the joy or the grief, which he desires to depict on the face, simply outlines the features, or attempts to copy shapes of a human body in any attitude? What kind of a sculptor would he be who knows nothing of the causes of the muscular shapes of the body, and discards a consideration of the causes of those shapes? Who can paint a maple leaf or a buttercup so well as he who has studied long their structure and the functions of their

Mr. Winchell. parts? Who can so well express an idea as he who understands that idea? The so-called "personal equation," therefore, is not at all a personal equation, but is an additional element of power, qualifying the topographer who possesses it the better to discharge the task he has to perform.

It is impossible for any topographer, whether equipped with a knowledge of geology or not, to measure the altitude and the size of every little knoll, and to fix on the hillside every little irregularity. He cannot delineate with perfect exactness the degree of slope on one side as contrasted with the degree on the other side of a ravine. There may sometimes be considerable areas which the exigencies of the case will not permit him to fully examine. He may have general data indicating unfailingly the form of a valley, but not detailed positive facts regarding its smaller shapes, or he may know the general shape of a subordinate hill without having measured it on all sides. If the topographer in such cases be also a geologist he is the more likely, in the construction of his map, to correctly fill in these lacking data. On the side of a hill he will know better whether the slope is gradual or abrupt, and hence he will more likely give the suitable shading by his contours. In fact, in general, throughout the whole work, the geologist topographer will work with the greater rapidity, and the greater correctness, and in the end his map will be fit immediately for the application of the geological colors.

The author calls attention to some of the deep-seated causes of the topography of the surface of the earth, and it is almost self-evident that he who understands those causes is the better qualified to express their effects in the form of topographical maps.

Mr. Williams. EDWARD H. WILLIAMS, Jr., Esq.—This paper is a forcible statement of truths which too often meet the engineer in the shape of a balance sheet where expense dwarfs income, because roads were unnaturally, in the sense of ungeologically, built. The writer does not propose to add anything to the array of facts so aptly marshalled, and will confine his discussion to a recital of instances which can be readily recalled by the older engineers of the Society, but which should be brought before engineering students in every collegiate course by the study of geographic geology.

Of the railroads uniting New York and Chicago, the New York Central and the Pennsylvania provide material for a competent discussion from a geologic standpoint. The former running on the base and altitude of a right-angled triangle has little difficulty in meeting the latter in speed in spite of the fact that it follows, as well as it can, the hypothenuse. This could be predicted by any geologist with a properly colored map of the States of New York and Pennsylvania, which showed the river systems, but omitted all topographic detail, as the former road follows the base level of the Hudson to

Albany, and thence is laid upon one of the geologic outcrops which Mr. Williams. cross the State from east to west and which offers little opposition to grading, while the latter, after traversing the great valley of Pennsylvania, crosses the repeated outcrops of the hard Oneida and Medina which form ridges springing abruptly from 800 to 1 200 ft. from the river bottoms, so that many detours to find gaps, and much tunneling, has imposed the angular plan of this great railroad. It is a magnificent feat of engineering; but it is a fight against Nature and not an attempt to accept Nature's aid. There are no natural east and west thoroughfares in this State, and but four north and south ones. The first by the Delaware level is followed by the Belvidere Division of the Pennsylvania; that by the Lehigh is occupied by the Lehigh Valley and the Lehigh and Susquehanna; that by the Schuylkill by the Schuylkill Divisions of the Pennsylvania and the Reading; and that by the Susquehanna by the Northern Central. On the other hand Nature offers unlimited inducements to northeast and southwest lines.

The geologist also can predict a relative cost of maintenance for two roads from a knowledge of the rocks of the region, and can select from two parallel valleys, offering similar gradients, the one which will "wear best" in retention of sides of cuts and fills, and in level and alignment of track. Pennsylvania gives many instances to prove this, and to show that while river gorges may be favorable as regards construction, they may prove expensive in the matter of maintenance. These are examples where the contour of the surrounding region affords ready collection and escape for rainfalls, and where the road-bed is permanently dry, as the drainage area disposes of its water either through underground conduits or delivers it across the road at a few places which can be effectively and permanently treated. On such a road, track grade and rail alignment are as permanent as on an ordinary permanent way, and speed does not endanger safety. On the other hand, there are roads through gorges which are bordered by sandstone regions of great porosity and monotonous surface, where all the rainfall is stored within the upper hundred feet of the mass and is regularly and persistently sent into the road-bed at millions of points, keeping it water-soaked and preventing maintenance of grade and alignment. Such roads are known from the fact that the outer rails of the curves are always pounded down, and the engineer who has to traverse the line on a fast train feels like offering a heartfelt thanksgiving if he reaches his destination in safety. For such roads no system of track drainage will suffice, and section gangs are always busy till winter freezes the bed into something like rigidity.

It is also a good thing for an engineer to know that in glaciated river valleys there is usually more or less quicksand lying under the hard till and against the solid rock, and frequently piling will strike the bouldery till and be smashed as if against rock; but heavy structures

Mr. Williams. subjected to shocks will show after erection that rock was not reached. A good example can be found in the 100-ton hammer of the Bethlehem Iron Company which was built on well-driven piling, but which sunk 4 ft. after erection. The extensive piling of the Lehigh Valley Railway at Buffalo showed how ineffectually surface contours indicated rock depths. The experienced engineer will therefore use extra judgment in glaciated regions.

These few instances show how important the subject of this paper is to an engineer, and the successful engineer of the future should know, not only how to locate his work, but how to locate it so that Nature will aid him in its building and take it under her protection. Too late he may know that Nature has resented his intrusion and in spite of his efforts is surely undoing his work.

Mr. Penrose. R. A. F. Penrose, Jr., Esq.—The paper sets forth the inevitable connection of topographic forms and geology, and shows clearly the utter folly of the many dogmatic and meaningless rules laid down by some topographers who are not geologists. It fills a long-felt want in giving scientific explanations for topographic forms, and it proves clearly the dependence of topographic forms on geology. The surgeon diagnoses external manifestations on the human body because he knows the internal structure of the body, and in the same way the geologist recognizes certain topographic forms as dependent on the nature and structure of the underlying rocks, because he knows the effect of natural influences on such combinations; but the topographer who is not a geologist is much the same as a surgeon who is not an anatomist. He knows the surface, but he does not know the causes of its phenomena, because he does not know the underlying structure. He can correctly delineate roads, township lines and all fixed points, but when he attempts to give character to the topography he utterly fails. Modern topographic maps are made largely by sketching in details between points and lines of fixed data. The character of these details depends on the geologic structure of the region and the nature of the underlying rocks. Hence, it is totally beyond the need of argument that a topographer who truly portrays Nature must also be a geologist.

Mr. Davis. W. M. Davis, Esq.—A good understanding of structural geology and of the origin of topographic forms is indispensable to the well-prepared topographer, for various reasons. This understanding might be dispensed with if the topographer had no limit as to time and expense, for he could then stake out every contour line and survey its course with great precision ; but it is obvious that, except in special cases, such a method is utterly impracticable. A few points on a contour line are all that can be instrumentally determined, and the rest of the line must be sketched in. In the work of sketching, some understanding of the forms to be sketched is of great service. There

Mr. Davis.

are occasionally persons who can observe and sketch so well that they can draw a good contour line without understanding the topographical features that it in part defines; but such persons are very rare, and they may be neglected when planning the education of topographical surveyors. Most students of this art will be forced to admit sooner or later that it is a very difficult thing to sketch a contour line accurately, and that every aid in this difficult work must be welcomed.

Then there is the important matter of generalization, always necessary in consequence of maps being on a smaller scale than Nature. Something must be omitted; something must be selected for representation; and much skilful judgment must be exercised in order to make this selection to the best advantage. The writer believes that a topographer who selects the more characteristic features for representation, and omits the trivial, accidental, unessential features, can make a much better map than a topographer who trusts to chance guidance in these matters. Appreciative generalization, required in the reduction to a smaller scale than that of Nature, is certainly a very difficult art, and should call science to its aid.

The accurate seeing that is needed in sketching between measured points, and the appreciative generalization needed in drawing on the map sheet, are both greatly aided, in practical work, by a good understanding of the subject worked upon. Hence, the writer often regrets that the young topographer is exercised so much more on his instruments than upon the real subject of his professional attention. He is, to be sure, much concerned with plane-tables and levels and transits; he must give some attention to the choice of good paper and ink; but the object of his most careful attention should be the earth's surface that he maps. He should approach the scene of his work with the same sympathetic interest in it that the artist feels on coming to the subject of his picture. Paint, brushes and canvas must all be well chosen and ready, but all must be held subordinate to the scene to be represented. Yet it is doubtful if the young topographer of to-day is inspired with any such feeling in his school of engineering. He is there overwhelmed with instrumental manipulations and logarithmic tables; even his instructors seldom have time to give close attention to the features of the earth's surface; and he seldom gains from them the proper spirit in which he should enter his professional career. There must be various practical reasons, so-called, for this deficiency in the training of the topographer. He generally has various other divisions of the large subject of engineering before him, and not knowing in which one of them he will have a chance for employment, he must needs make some preparation in all. So with the faculty of engineering schools, there are so many technical subjects needing attention that physical geology and geography are crowded to the wall; at best they are in charge of some one who gives to them his second attention,

Mr. Davis. directing his first and best thought to some more "practical" subject. If this condition of things were explicitly admitted to be unsatisfactory by those who direct our schools of engineering, there would be more hope of reform; but the few inquiries that the writer has made have not discovered any serious dissatisfaction with the existing order of things. So it must be expected that, for many years to come, topographers will be turned out of engineering schools with only about the same measure of understanding of topography that they now have.

The members who read these lines may, in reply to these criticisms, perhaps urge that the writer is not a topographer, but a geographer; and hence that he has no practical experience on which to base his statements. Unfortunately, this is in good part true, as far as map-making is concerned; but on the other hand, he has had a good deal of experience in using maps, and in this way he frequently has occasion to lament the inexpressive drawing of hachures or contours. A morainic surface, where the little undrained pools or swamps were the key to the character of the district, has been represented in most misleading style as having everywhere a free and mature drainage. A valley floor, on which flat alluvial fans are spread out by small side branches, has been contoured without any proper appreciation of the visible convexity of the fans, in consequence of which the contours should turn down stream, not up stream, in crossing them. Sharp-edged cliffs have been rounded off, losing their essential quality of freshness; and whether this obliteration of essential details was the fault of the topographer, the draftsman, or the engraver, it nevertheless passed the scrutiny of an institution whose maps are on the whole justly celebrated for their accuracy.

There is to-day a practical difficulty, in the way of the education of the young topographer in physical geology and geography, in the absence of a good text book, directed especially to his needs. Until such a book is forthcoming from among our geologists and geographers, the schools of engineering may perhaps feel that the responsibility for the defect in the topographer's education does not lie with them. The writer would, therefore, be personally gratified if among the results of this paper and the discussion following it, there might be found the inspiration to some well-qualified expert in geology, geography and topography, to produce the needed book. The existence of such a book would go far towards inducing a good course on earth forms in engineering schools, where little attention is paid to that subject now.

Mr. Stevenson. JOHN J. STEVENSON, Esq.—Not a few engineers may be inclined to think a discussion of this sort somewhat irrelevant, but the relations of geology to topography and to practical engineering work are too intimate to be ignored. The geologist is often surprised by the readiness of men, trained in observation, to overlook striking features of topog-

raphy and of geology. Diagrams are not unknown showing rocks dipping in different directions where there is no variation; showing an abrupt slope on the wrong side of a ridge and showing a rounded crest where only irregularity can exist. Mr. Stevenson.

A rapid geological reconnaissance of a region with not very complicated structure is the best preparation for making a detailed topographical map of it for use by railroad engineers. Hard rocks give ridges, soft rocks give valleys. A geological profile tells where to expect the hard or the soft rocks; it exhibits the folds and their direction as well as the rate of dip on both sides. Given now the drainage arrangement, the topographer, with even moderate knowledge of geology, is prepared to sketch in the relief, and to give a map which can be utilized in the office for determining lines of preliminary survey. It can be utilized even for tentative determination of cost of construction, as the distribution of hard and soft rocks along any given line can be ascertained approximately. In many cases the true conditions are different from the apparent, for the only rocks extensively exposed on a ridge may be soft, whereas the core is most likely to be hard. The writer knows of one case where a firm, by the advice of an engineer, contracted for a long tunnel on the basis of soft rock throughout, though midway it passed through about 1 500 ft. of very hard sandstone, a fact which would have been discovered quickly enough if the adviser had possessed even a moderate amount of geological knowledge.

The indifference of the observer to the varying forms of relief due to erosion of rocks of different hardness may lead to financial disaster. About twenty-five years ago, it was proposed to construct a railway in order to obtain cheap iron ore. The expert discovered that the cost of construction along the valley where the ore had been dug would be very great; but he found on the other side of one of the bounding ridges what he believed to be the same ore-bearing rock, and advised that the road be constructed on that side, as the cost would be very much less. Happily for the projectors, the panic of 1873 prevented them from building the road, for the rocks are not the same—one is ore-bearing, the other not, and the ridge between them is abrupt. But the ridge itself tells the story by its form, and tells it so well that a geologist, notwithstanding the close resemblance of the two rocks, would be led to doubt their identity and to make close investigation.

The "surface creep" is a factor in topography and in engineering to which the author has not alluded. This is the downward movement of superficial portions of a slope, giving a rudely benched outline to mountain valleys. It is by no means an uncommon phenomenon in the Appalachian region, occurring ordinarily well up a valley, along an inviting line for a railroad and too often at about the place where the

Mr. Stevenson. tunnel should enter; but nothing can be conceived much worse for a portal than the 200 or more feet of crushed rock, which is liable to be folded in such way as to have the axis of the fold coincident with that of the tunnel. Yet such a feature as this, familiar enough now to geologists, is almost certain to be overlooked by the ordinary observer in preparing the map.

The relations of dip to topographic structure are very intimate and the rule respecting them is so simple that one with even modest geological attainments is not likely to err. But how dangerous ignorance of geology may prove in leading to false generalizations is shown in an otherwise very admirable paper, presented to this Society several years ago. The author laid down some very definite rules respecting directions of slopes, but the rules were purely empirical, applicable where he had observed and wholly inapplicable where rocks dip in any other direction. One, proceeding upon rules such as laid down in that paper, would produce a map with some slopes right and others wrong, for he would find what he looked for, and his map might lead to the waste of much time and money in preliminary surveys.

Mr. Van Ornum J. L. Van Ornum, Assoc. M. Am. Soc. C. E.—This paper is a substantial addition to semi-technical literature. Undoubtedly a knowledge of the science of geology is, at times, of the greatest importance in engineering plans. The writer's own experiences on reconnoissances have shown him the advantage of an understanding of geological principles on such expeditions. Plainly a knowledge of geology has contributed definitely to the development of the diversified and elaborate systems of water supply of Western Europe. Other instances of the direct application of geological knowledge to engineering undertakings will occur in the individual experience of every engineer. In certain fields of topographical engineering this concisely comprehensive paper will offer real assistance. Nevertheless, the writer cannot agree that geology is a necessity to the scientific topographer. Were the word topography given its primary meaning, the "delineation and description in minute detail of any place or region," its generality would make it include subsurface as well as surface characteristics, and would thus include geology as an essential; but if there is given to topography its later, more technical, more definite and better meaning—that of a faithful representation of the earth's surface features—the incorporation of its internal structure is excluded. This latter meaning is also adopted by the author, in the beginning of the seventh paragraph of the paper, and this understanding of the term gives definiteness to its consideration.

At the end of the third paragraph the author compares the topographer ignorant of geology to the surgeon lacking anatomical knowledge; and yet the work of the latter is internal, while the study of the former concerns the surface. A truer parallel might be that of the

Mr. Van Ornum

sculptor, whose labor is to delineate truly the external appearance, interesting himself with subsurface development only so far as it aids in giving true expression to the exterior; and even then, in the nation which excelled all others in sculpture, and the work of which is still considered the truest and best, Phidias wrought with master hand a hundred years before Aristotle's researches revealed the crudeness of Grecian anatomical knowledge and placed that science on a basis of scientific truth.*

Dropping the simile, the writer's practical experience on topography has been quite different from that mentioned in the paper. This experience has demonstrated to him that the exact methods available for topographical work inevitably show a cliff where a cliff occurs, a ridge where a ridge is encountered, or the descent and sinuosities of a torrent as its meanderings actually occur in Nature. In short, the scientific methods, the application of mathematical principles, and the instrumental precision, under the command of the engineer for a topographical survey, make absolutely fixed and reliable (within the limits of representation of his map) the relative position and elevation of every surface feature of the terrene. Such topographical methods and control reduce to a mathematical exactitude the process of delineation, which becomes, primarily and essentially, simply a question of applied mathematics. Of course, other knowledge, the more extensive the better, is often useful; but the writer is here speaking of primary essentials. To advert again to the comparison, the scientific methods of exact topography render its representation comparable to the taking of a plaster cast of the human subject, which is essentially independent of the internal structure.

There should be an exception made if to topography is given a more general significance, that involving approximate and inexact representation, which is an unavoidable result of the hasty methods that are practicable on reconnoissances, and which also follows the procedure depending upon the occupancy of occasional points only and from them "sketching in" all the area by eye, or by other estimation of distance, direction and elevation. While such representation is occasionally useful to engineers, it probably misleads them fully as often as it aids, as in the case of the Massachusetts Lake, which was shown as having its outlet to the east when in reality it was from the western side. In cases where these inexact methods are the best that circumstances permit, or are deemed sufficient for the purpose desired, the writer most earnestly advocates an indication of its approximate character, by means of the style of delineation chosen, or by explana-

* "Two leading facts may be admitted with certainty. The first is that, previous to the time of Aristotle, there was no accurate knowledge of anatomy * * *; among the services which the philosopher of Stagira rendered to mankind, one of the greatest and most substantial is, that he was the founder of Comparative Anatomy" [Encyc. Brit. (1875), Vol. I, p. 800].

Mr. Van Ornum tory note, in order that none referring to such maps may be unwittingly misled, as well as for the sake of the topographer's reputation.

For many engineering works the topographical survey is a prerequisite. In questions of water supply and transmission, sewers, railway location, drainage, highways and other public improvements it is of increasing importance. To be of value to the civil engineer the survey must be entirely reliable. Such accuracy is obtainable only by employing the exact methods of topographical delineation widely used and thoroughly proved, which are, in the writer's judgment, primarily and essentially independent of geological formation and structure.

Mr. Lyman. BENJAMIN SMITH LYMAN, Esq.—The author has done a very useful piece of work in setting forth so clearly, forcibly, methodically and compactly the essential, elementary principles of the origin of topography; principles that are so apt to be overlooked or wholly misinterpreted by many civil engineers and others who have to deal with, or at least observe the finished results of, topography-forming causes. He has well pointed out the absence of anything supernatural, miraculous or cataclysmic in the most stupendous topographical forms, and how they are simply the work of the same every-day agencies of water, air and temperature that are now to be seen acting upon the rocks and the earth. He has shown how the result accomplished by those agencies varies with the material they work upon, according to the comparative hardness of the different rockbeds, and according to their position or geological structure and certain other conditions.

He has not gone very fully into the effect of geological structure. That is not so obvious, to be sure, in its influence, but is perhaps the most important of all the conditions and the most striking, characteristic and useful in the indications it impresses in a large way upon the topography. That subject, however, was very ably and somewhat elaborately, though briefly, discussed by Lesley and H. D. Rogers forty years ago, when it was a novelty to the scientific world. It is very gratifying to find the seeds they sowed not only growing vigorously, but already yielding more and more abundant fruit. Their subject—The Way the Topography is Influenced by the Geological Structure of a Series of Rockbeds of Different Hardness—is indeed the only part of the whole matter that is not rather obvious to anybody who has given a little attention to geology, and consequently it was perhaps all that was worth discussing, except to beginners.

Notwithstanding the excellence of the paper, the writer begs to take exception, in some degree, to one of the author's emphatic remarks, namely: "To set a man at work on topography who knows nothing of geology is very like having some one perform a surgical operation who knows nothing of anatomy." He adds: "It is of the utmost importance to the topographer that he should know what kind

of topography to expect;" and he declares that the object of his paper is "partly to show the necessity of a knowledge of geology to the topographer." Mr. Lyman.

Such expressions might perhaps be unduly discouraging to a topographical engineer imperfectly acquainted with geology and yet more ignorant of the geological structure of the field he is sketching. Unquestionably it is desirable that a topographer should know that soft rockbeds are apt to occasion depressions in the surface of the ground, and that, for example, in a coal region a terrace or a narrow hollow, like a groove or crease in the surface, may be caused by the outcrop of a coal bed. If he is aware of the importance of such topographical variations, and is consequently on the lookout for them, they will appear in his mapping and be serviceable as indications of the underlying geological structure.

It is true that, just as a knowledge of anatomy is useful in drawing an imaginary human figure, a good knowledge of geology might be necessary for making a rational and consistent imaginary topographical sketch; but a picture of an actual human figure may be made without much anatomical knowledge, and without understanding whether, for instance, a protuberance indicates the presence of a bone or is merely a wen, or without being aware of the cause of a depression. Indeed, the sculptor of the recently famous Bacchante Statue, is said to have copied his model so faithfully, yet in such unconsciousness of the anatomical or physiological causes of what he saw, as to have shown above the knees slight hollows made by the pressure of garters. However incongruous the result may be for the imaginary subject, it is an excellent copy of the actual woman. In the same way, as the topographer needs to reproduce actual facts, he may be accurate without knowing the geological causes of the forms he copies. Indeed, he may be more accurate and unprejudiced than if he imagined that he understood the geology of the place and sketched the surface as he thought it ought to be in order to agree with his idea of the geology. As it is very often quite impossible for the most skilful geologist to know even in a general way the underlying geological structure at the time when the surface is sketched, it is best to aim at the utmost freedom from prejudice in sketching, so as to make a picture as faithful and unbiased as if photographed by the wholly impartial sunlight.

A good illustration of the excellent geological indications of topographical work that was doubtless done without any knowledge of its geological bearing is to be seen in the admirable map of the salt range and the neighboring country in the Punjab, made for military purposes about forty-five years ago by engineers under the guidance of Captain D. G. Robinson. Many portions of the map show how distinctly the numerous strongly contrasted and persistent variations in hardness of the rockbeds have caused the geological structure to be indicated, even

Mr. Lyman. in some cases where it is very irregular and much broken up, and most unlikely to have been suspected or considered by the topographer. One such difficult portion of the map is photographically reproduced in Plate II.

At the southern edge of this fragment of the map, there is evidently a basin, with its inner shallow part bounded by a narrow ridge of somewhat rectangular course much broken down on the eastern side, owing to the nearness of the large stream that traverses the basin from north to south. To the east of this inner basin the rocks plainly dip steeply, about vertically, westward, with two or three principal narrow ridges and a number of smaller ones between, separated by small narrow valleys. To the northeast of the central basin, those outer ridges are broken into sharp angular and rather confused forms somewhat resembling the prow of a ship, one enclosing another. To the west and northwest of the central basin, the rocks dip less and less steeply eastward, forming little hills with a gentle eastern slope and an abrupt western escarpment, and with the crests of the narrow ridges so worn down as to leave little peaks between the small cross-cutting valleys. Northward in the main valley of the river, later horizontal soft beds, apparently more or less recent alluvium, in great part cover up the underlying steep-dipping harder rocks, and leave the country in the main a nearly level plain. The small narrow ridges that rise above that horizontal alluvium, as well as the ridges adjacent to it, show that the rockbeds not only dip steeply, but with some sudden changes of direction, as if those lower hard rocks had been strongly compressed into basins and saddles and here and there quite crushed and broken into irregular shapes; yet in some cases with the sharp, almost angular, curves of successive beds nearly parallel to one another, even where rather far apart.

It is clear, then, that while a knowledge of some of the simplest topographical effects of geological erosion may be useful to the engineer, so that he may be on the lookout for them, it is not necessary that he should have anything like a thorough geological training and still less that he should be aware of the geological structure of the place he is sketching.

Mr. Branner. JOHN C. BRANNER, Esq., Ph. D.—In so condensed a statement of the case it is not possible to go into details or to mention the exceptions that may be found to every rule. That there are exceptions to rules for topographic forms no one knows better than the author; indeed, one of the chief objects of the paper was to point out the fact that the rule for one place is inapplicable in another place.

The most common objection one hears to the theory here set forth is that surface forms are ascertained by instrumentation, and that it is only necessary to have this work well done in order to produce a good topographic map.

TOPOGRAPHY INDICATING GEOLOGICAL STRUCTURE.

PART OF A MAP OF THE PUNJAB SALT RANGE AND NORTHWARD,
BY LT. D. G. ROBINSON, BENGAL ENG'RS,
1851–57.

ORIGINAL SCALE:– 1 MILE TO AN INCH.

0 1 2 3 4 MILES 5

Professor Davis touches the vital point of this objection when he points out that the topographer cannot stake off and run out his contours. He is limited as to time, means and data, and his map must be made within the limitations imposed. The fact that there is now and then a topographer who is able to make excellent maps without having studied the reasons for topographic forms cannot be accepted as determining the best training for the common run of students. Such men are quite the exception. Mr. Branner.

Under the head of geologic agencies influencing topography, one item of considerable importance was not mentioned: the influence of joints on the rocks. Good illustrations of this influence may be found in Dutton's "*Geology of the High Plateaus of Utah*," plates VII (op. p. 253) and X (op. p. 280), and in Daubrée's "*Géologie Experimentale*," pp. 324–373.

An excellent illustration of the influence of climatic conditions on topography is found in the "Knobstone" of Indiana. Professor John F. Newsom, of the University of Indiana, who has been working upon the geology of this formation for several years, has informed the author that this rock is highly susceptible to weathering influences; so much so that the south-facing slopes are, as a rule, gentle, while those facing the north are abrupt. An article by J. T. Campbell* offers a different explanation for the topograpy of the "Knobstone," but the author's own observations on this rock agree entirely with those of Professor Newsom.

* American Naturalist, Vol. XVIII, p. 367.